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Technical Memorandum

U.S. NAVY FLIGHT TEST RESULTS WITH THE LTN-211 ONS

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Evaluations have been completed of LTN-211 Omega/VLF Navigation System trial installations in U.S. Navy KA-3B and P-3B aircraft. System accuracy was determined in relation to visual sightings over surveyed landmarks during 37 flights totalling 129 hours. Navigational accuracy achieved is given in terms of sample statistics and population estimates. Performance using Omega signals (only) is compared to that achieved when augmented by use of the Navy VLF communications signals.

PREFACE

This Technical Memorandum was prepared for presentation at the Sixth Annual Meeting of the International Omega Association 18-20 August 1981 at Montreal, Canada. The subject material derives from data accrued during AIRTASK's under which NAVAIRTESTCEN investigated application of the LTN-211 Omega/VLF Navigation System to selected Navy aircraft installations and missions, including the KA-3B and P-3B airplanes. Complete test results are contained in formal NAVAIRTESTCEN reports released under applicable AIRTASK directives.

APPROVED FOR RELEASE

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BACKGROUND

In 1978 the U.S. Navy began investigation of the potential use of commercial "off-the-shelf" Omega Navigation System (ONS) designs in Navy air applications. The initial impetus for this interest was the need for functional replacement of LORAN-A in the A-3B fleet, a relatively old twin-engine jet transonic carrier-based aircraft now used for electronic intelligence, tactical electronic warfare, VIP transport, and aerial refueling missions. A potential application in P-3 type aircraft, a four-engine turboprop land-based airplane designed for extended duration overwater patrol missions, was also foreseen.

Candidate ONS designs meeting the ARINC 599 characteristic were considered. Source selection criteria were established to minimize risk and cost. Trial installations of the selected ONS were to be flight tested to verify functional suitability and compatibility with the A-3B and P-3B systems.

Selection criteria and the Navy test program have been previously described (Sakran, 1980). The ONS selected for test was the Litton Systems, Incorporated, Aero Products Division, Model LTN-211. This system is compatible with the ARINC 599 characteristic. Because of installation constraints in the A-3B airframe, the Navy opted for the smaller "brick" shaped H-field antenna coupler unit vice the streamlined ARINC shape antenna.

FLIGHT TESTS

The U.S. Naval Air Test Center at Patuxent River, Maryland, was tasked to perform installation verification and limited performance flight tests of the LTN-211 installations in KA-3B and P-3B airplanes. Interim test findings were reported last year (Sakran, 1980) and final project reports have been disseminated (Concannon, Mora, Sakran, and Beal, 1981; Mora, Sakran, and Reed, 1981).

The scope of flight trials is summarized in table I. Figure 1 shows the various routes flown. Actual aircraft position was estimated by visual mark-on-tops at low level (3,000 feet above terrain) over landmarks of known surveyed position such as navigation aids, radio towers, and bridges.

Table I

Scope of ONS Tests

	KA-3B	P-3B
First Data Flight	26 Sep 79	5 Mar 80
Last Data Flight	17 Jun 80	30 Aug 80
Number of Flights Completed	26	11
Total Flight Hours	65.7	63.7
Number Position Fixes	504	334

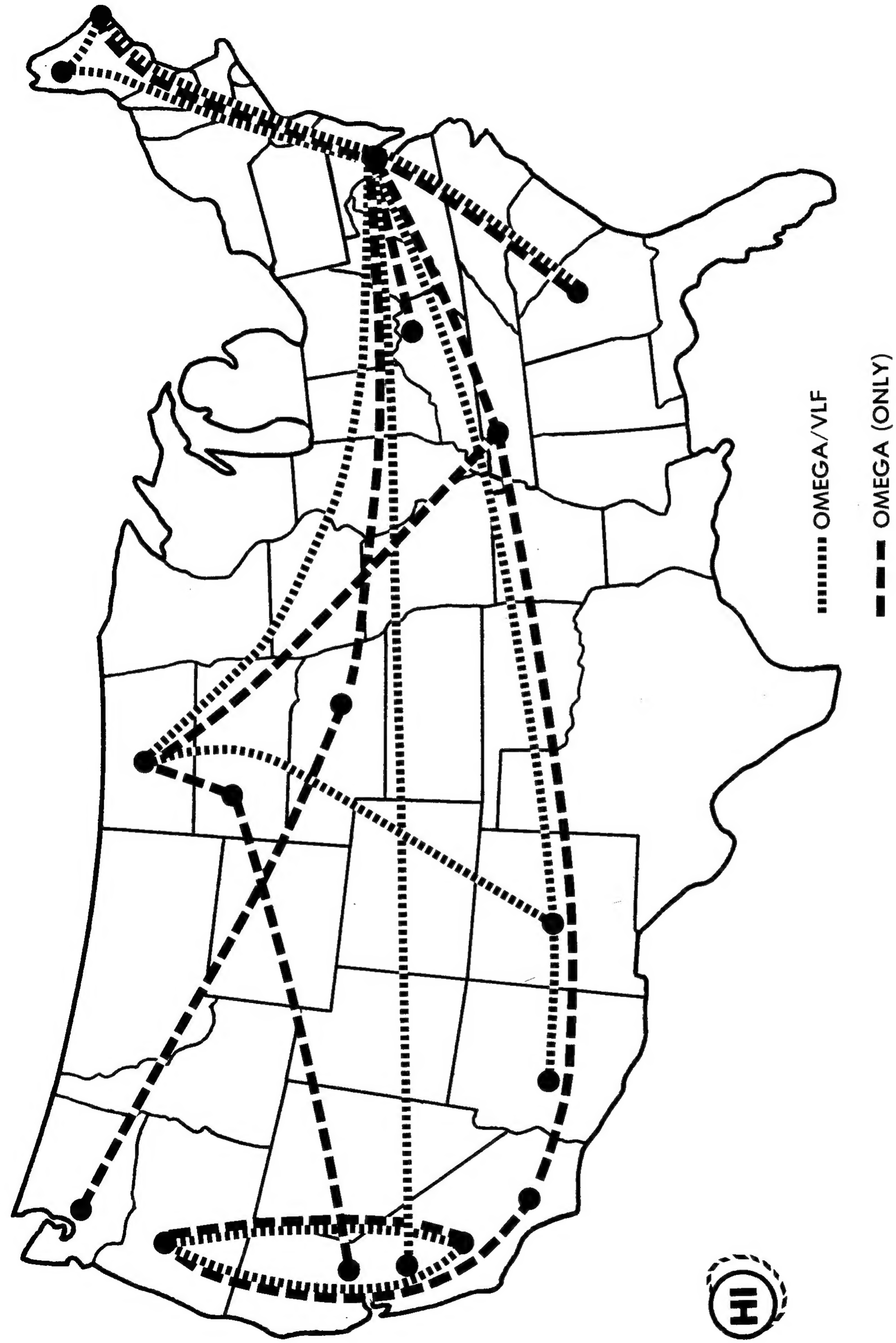

Figure 1: Geographic Coverage of Low-Level Navigation Test Routes.
Flights included operations in proximity to Omega C (Hawaii) and Omega D (North Dakota) and to VLF communications stations NAA, NLK, NPM, and NSS.

The Trinidad Omega signal, which was available during this time period, was manually deselected and at no time used in the navigation solution. At least one, sometimes two, other Omega stations dominant in the test area were manually deselected during most flights. This was done in order to ensure the ONS installations had sufficient sensitivity margin to be usable under suboptional signal conditions such as transmitter outages.

VLF AUGMENTATION

The version of LTN-211 ONS evaluated included a VLF option consisting of a receiver-converter, tunable under software control, and necessary software to use measurements of the relative phase of transmissions from the Navy VLF communications transmitters. Shift of VLF carrier phase relative to the ONS clock is mapped into position displacement of the ONS location relative to the great circle radial from the transmitter site. The LTN-211 tracks four VLF communications signals selected by software from a library of nine transmitters and three possible modulation modes. Communications signals are admitted to the navigation solution only after complete initialization has been established using a combination of manually entered position and the absolute phase measurements of the 10.2, $11.\bar{3}$, and 13.6 kHz Omega signals. No correction for diurnal propagation phase delay is applied to the VLF communication signals measurements.

Utilization of VLF communications station transmissions to augment the Omega Navigation solution is claimed to increase navigation reliability by providing greater signal redundancy, fill in geographical gaps in Omega coverage, and possibly aid the ONS in tracking aircraft dynamic maneuvers. Advantages gained with VLF inclusion have been elucidated (Gibbs, 1976; White, 1980). There remains the operational consideration, however, of dependence on transmissions which are not dedicated to navigational service and which consequently cannot be guaranteed to be continuously available. Therefore, it was desirable to verify that signal reception reliability and navigational accuracy could be maintained using only the dedicated Omega transmissions. This was accomplished by manually deselecting all VLF communications signals during some flights.

NAVIGATIONAL ACCURACY

For the following discussion, data from the KA-3B and P-3B flights were pooled in order to obtain a larger sample for analysis. This is justified as the experimental procedures, aircraft dynamics and ONS aiding inputs (heading and true airspeed) were similar. The pooled data were partitioned as a function of whether the VLF communications signals had been deselected, thus allowing comparison of the normal "Omega/VLF" navigation mode position accuracy with that achieved in the "Omega" (only) mode.

A proper comparison would call for strictly identical flight routes, maneuver dynamics, and signal conditions, preferably by means of flying dual ONS installations side-by-side. Since the intent of these trials was only to demonstrate that the Omega mode was functioning adequately, the two mode samples are not strictly equivalent. The size of the pooled data, however, suggests that there may be validity in comparing the modes on a statistical basis.

Sample Statistics

Edited from the original data were initialization points and any fixes logged with the ONS displaying an indication of operation in a degraded mode (dead reckoning, ambiguity detected, two-station rho-rho navigation, or navigation using only the VLF communications signals). The following analysis thus represents navigational performance when the LTN-211's software criteria for normal operation were met and no alerts or warnings were displayed.

The edited data sets comprised 475 sample points spanning 80.8 hours (25 flights) of Omega/VLF mode navigation and 208 sample points spanning 48.6 hours (12 flights) of Omega mode navigation.

Figures 2 and 3 show the sample distributions of radial position error for the Omega/VLF and Omega modes. The sample median radial error is the most robust statistical estimate of the population circular error probable (CEP). The CEP is defined as the radius of a circle centered at the true position which includes 50 percent of all (infinitely many) ONS position fixes. The higher percentiles of the median-ranked sample data are also estimators of the population percentiles. Under the assumption of a random sample, but from an unknown population distribution, confidence ranges on the sample percentiles can be estimated (Emmerich, 1967) on the basis of sample size.

Root-mean-square (rms) radial error for Omega/VLF mode navigation was 2.20 nmi. The sample median was 1.48 nmi and the sample 95th percentile was 4.39 nmi. Maximum observed error was 8.98 nmi. At the 95-percent confidence level, the corresponding population CEP is between 1.38 and 1.55 nmi, and the population 95th percentile is between 4.11 and 4.52 nmi.

RMS radial error for Omega mode navigation was 1.82 nmi. The sample median was 1.24 nmi and the sample 95th percentile was 3.26 nmi. Maximum observed error was 10.78 nmi. Population estimates at the 95-percent confidence level for the CEP are 1.20 to 1.29 nmi and for the 95th percentile 3.03 to 3.55 nmi.

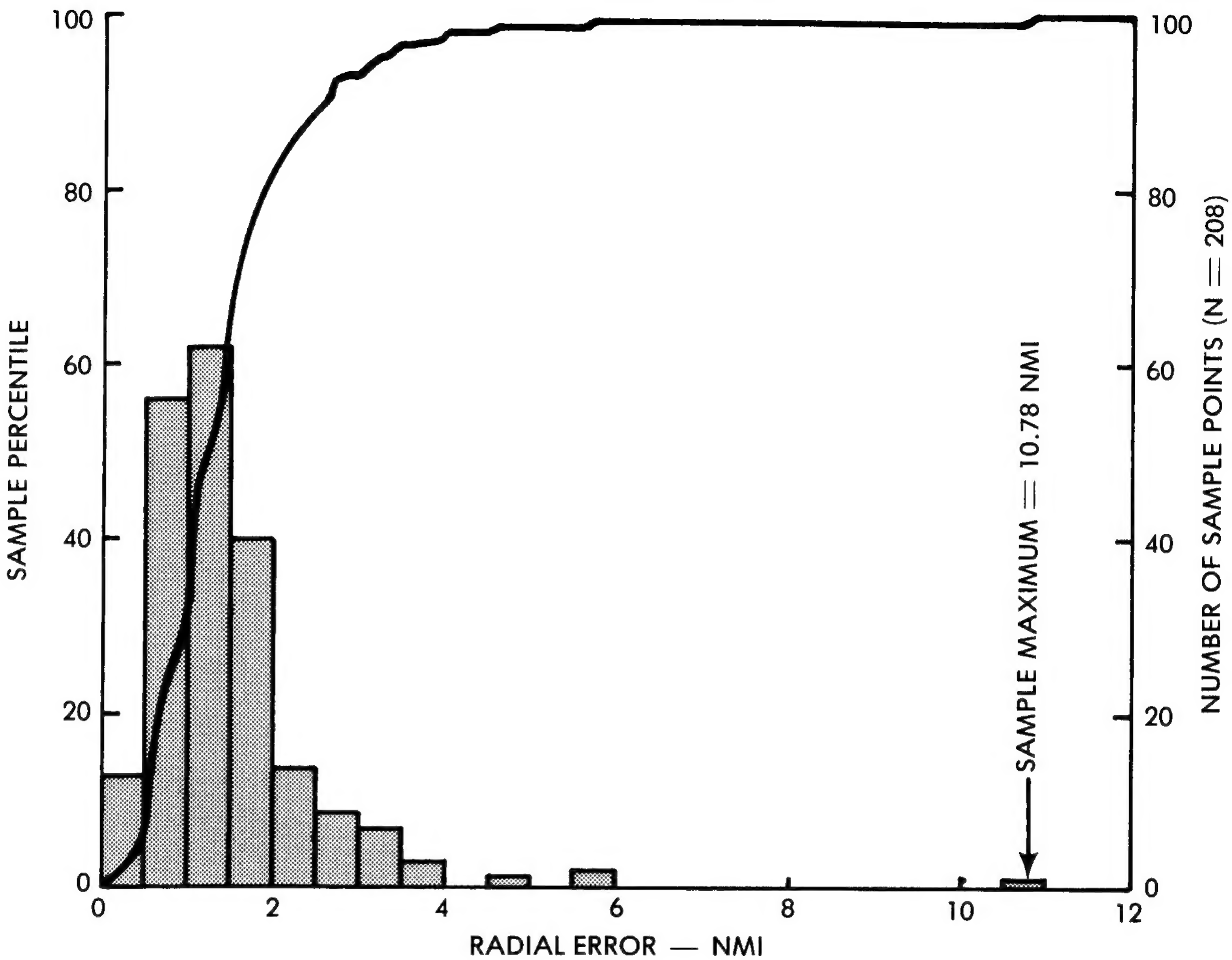

Figure 2: Sample Distribution of Radial Error in Position Indicated by LTN-211 ONS Using Omega Transmissions Only

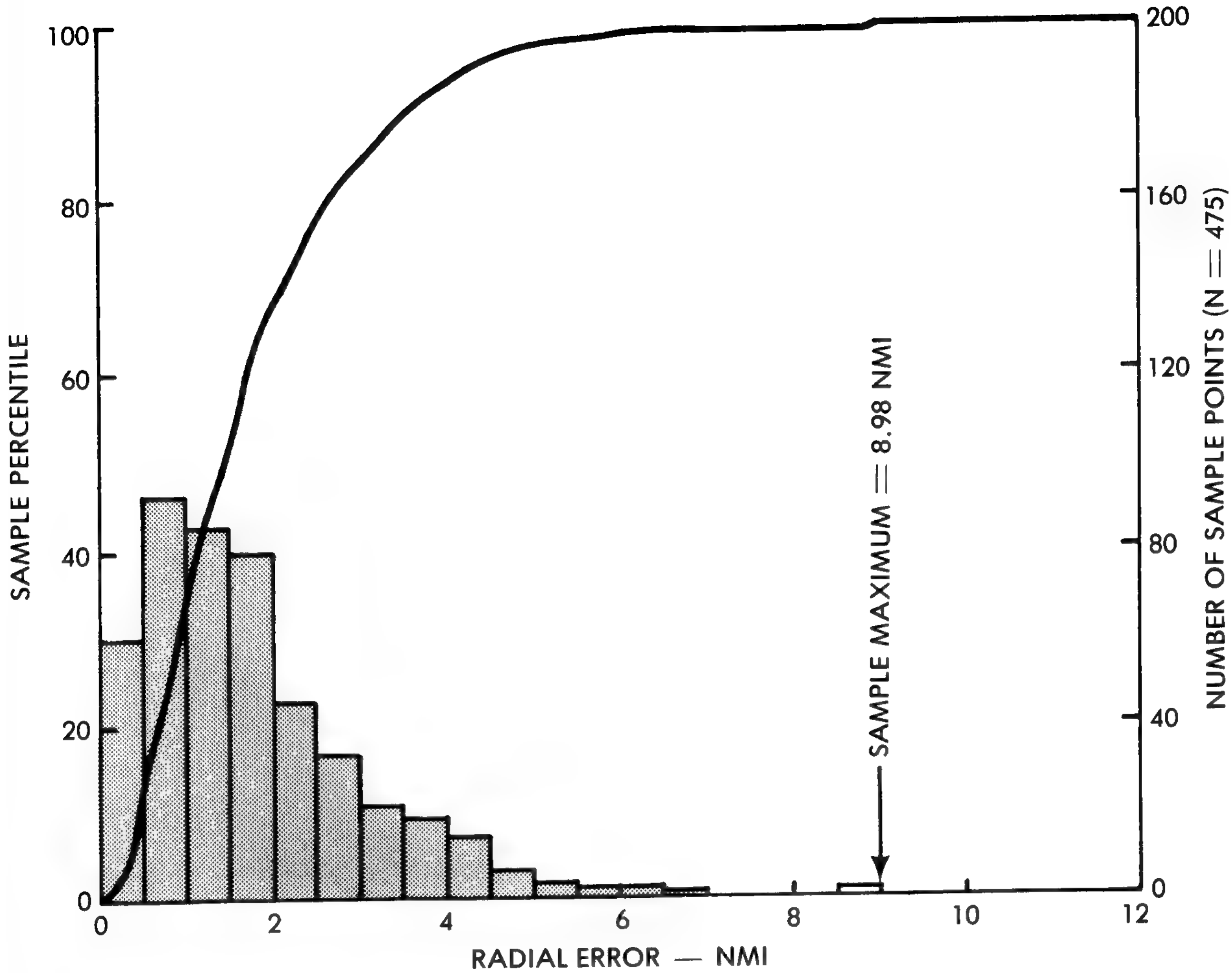

Figure 3: Sample Distribution of Radial Error in Position Indicated by LTN-211 ONS in Normal Omega/VLF Navigation Mode

Population Estimates

Figure 4 again plots the cumulative distribution functions (CDF) of the two radial error samples, this time on a non-linear grid such that CDF's conforming to a Weibull probability function plot as straight lines. The Weibull distribution was first suggested as a model for navigational radial error variates by Baker (1967) and has been found to fit experimental samples of Omega radial position error (Sakran, 1975). In its two-parameter form, the Weibull CDF of radial position error R ($R > 0$) is

$$\mathrm{CDF}(R) = 1 - e^{-(R/B)^C},$$

where B and C are positive constants. The parameter B is a scaling length equal to the 63rd percentile value of radial error. The dimensionless parameter C controls the shape of the distribution. Two special cases are of particular interest. When $C = 2$, the Weibull is identical to the circular normal (Rayleigh) distribution. When $C = 1$, the Weibull simplifies to the exponential distribution.

Maximum likelihood fits of the Weibull parameters to the experimental data are shown in figure 4 as straight lines. For the Omega/VLF mode, $B = 1.93$ nmi and $C = 1.45$. For the Omega (only) mode, $B = 1.59$ nmi and $C = 2.08$. Goodness of fit is evident by the closeness of the sample points to the lines.

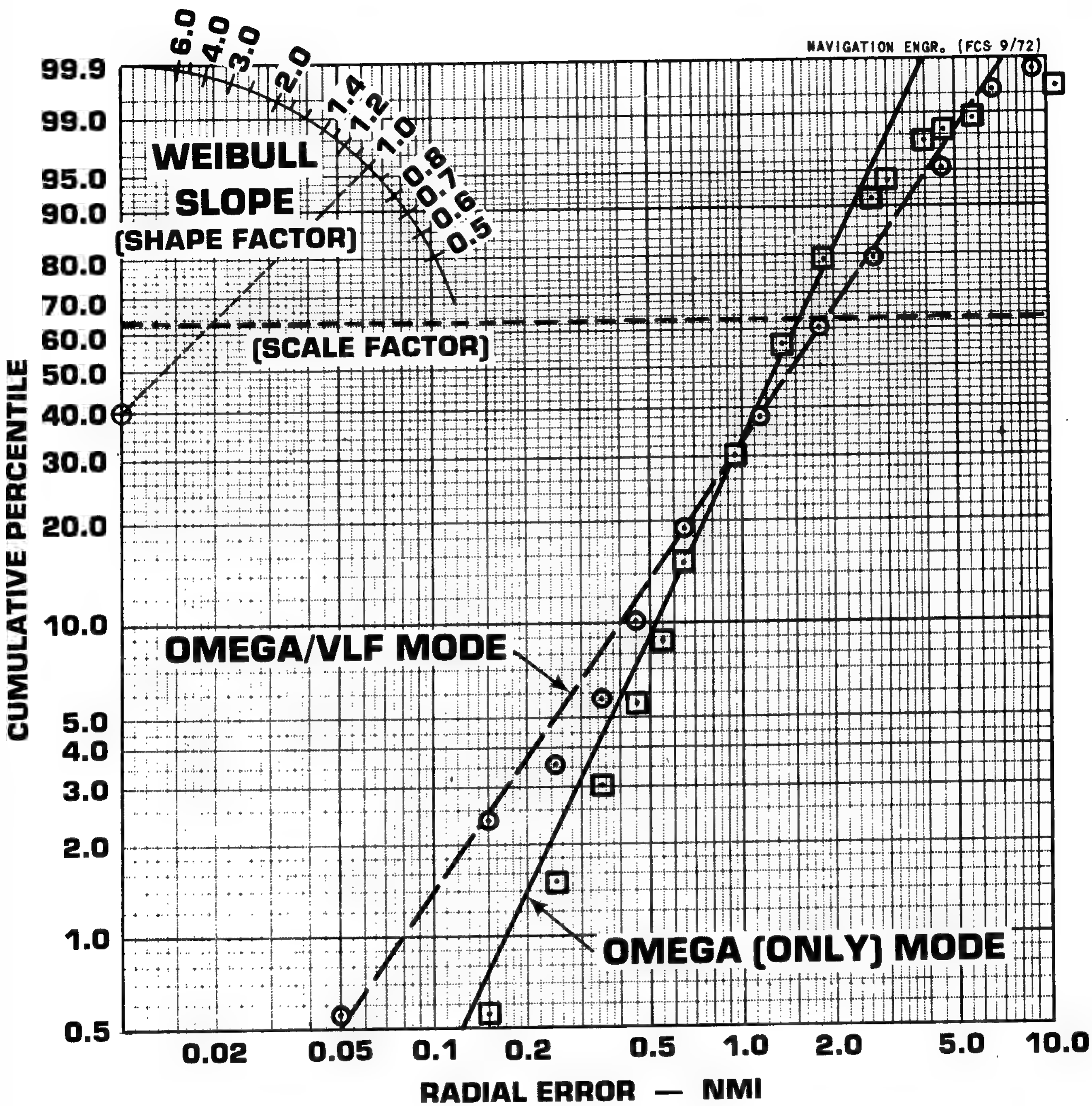

Figure 4: Radial Error in Position Indicated by LTN-211 ONS.
Straight lines represent maximum likelihood fits of Weibull distributions to the sample data. Isolated points show representative median-ranked sample percentiles.

The Omega mode data are best fit by a distribution having a slope (C = 2.08) essentially that of the classical Rayleigh distribution (C = 2). This is a pleasant outcome since the theoreticians are fond of reducing the real world to the analytically tractable case of zero mean error and equal variance in every direction. However, the fitted line matches the experimental data only up to the 90th percentile, not of much use for the practicing navigator who would prefer to predict the outcome of his flight with somewhat greater reliability. Reviewing the data points comprising the top 10 percentile errors produced likely explanations for many of the apparent outliers. These explanations included operation immediately prior to entering or leaving the dead reckoning mode, position fixes displayed immediately following operator command of the lane resolution function, fixes taken during local sunset transition and with one dominant Omega station off the air, and a suspected intermittent equipment problem. In other words, there existed physical reasons for the top 10 percentile error fixes to be disparate from the dominant distribution.

One could argue that the ONS's warning annunciator logic should be tightened to reflect these conditions and thus alert the user that the set has departed from statistically predictable behavior. This redesign is probably unwarranted since the observed errors were not excessive for the intended applications. When in the Omega mode, the ONS remained stable (i.e., at no time did it exhibit diverging error growth).

The Omega/VLF mode sample is remarkably well-matched by the Weibull CDF through the 99.6th percentile. Only the single highest error sample point departs significantly from the idealized distribution. The slope parameter C = 1.45 is halfway between the exponential and Rayleigh values so that the distribution's tail decays less rapidly than that of the Omega mode. This causes the Omega/VLF error to exceed that of the Omega mode above the 30th percentile. The Omega/VLF mode data were internally consistent, however, whereas the larger Omega mode errors deviated from a simple statistical model.

CONCLUSIONS

Inclusion of the VLF communications signal measurements in the navigation solution changed the statistical distribution of radial error from a Rayleigh distribution to a form between the Rayleigh and exponential distributions. The VLF measurements significantly increased the reliability and statistical consistency of the navigation solution but with the cost of a degradation in accuracy.

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